Measuring Charm and Bottom using the PHENIX Silicon Vertex Detectors

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Abstract.
The PHENIX experiment at RHIC has embarked on a broad range of upgrades to enhance its physics reach. One of the upgrades consists of a set of Silicon vertex trackers that combine to cover the pseudorapidity range -2.4 to 2.4. A description of the vertex detectors and some of their physics goals and capabilities will be given, as well as technology choices and results from prototype components.

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1. Introduction

The study of heavy quarks (c and b) in heavy-ion collisions offers unique opportunities for the study of the properties of the QGP. Heavy quarks are produced in hard collisions early in the event, and they probe the produced medium as they propagate through it. QCD calculations involving heavy quarks are more accurate than those involving light quarks. The heavy quarks eventually hadronize into D and B mesons, which in turn can decay semileptonically to electrons or muons. Although the PHENIX detector has excellent electron and muon identification capabilities, the decay leptons of interest occur against a very large background of electrons and muons coming from the decay of pions and kaons, from the decays of J/Ψ, and from prompt muons and electrons from the primary vertex. The Silicon vertex detector will make possible a large reduction in these backgrounds by determining the origin of the leptons. This will enable the study of the production and flow mechanisms of heavy quarks, and investigations into the production and suppression of quarkonia. The device will also be able to measure the reaction plane, and improve the tracking of high-pt particles, and help elucidate the quark and gluon contributions to proton spin.

The D and B mesons have finite lifetimes, with cτ of a few 100 microns. The leptons resulting from decay of these mesons typically will not point back to the event origin, but will have a small but measurable distance of closest approach (DCA) to the promary vertex. If pions or kaons decay to leptons, they do so after traveling a much larger

distance. By contrast, leptons coming from J/Ψ decay will appear to come directly from the primary event vertex. Thus by using a silicon vertex tracker to measure the distance of closest approach (DCA) of a candidate lepton to the primary event vertex, one can strongly suppress the background and obtain the desired c→D→ μ/e and b→B→ μ/e samples.

The device under construction consists of a barrel section (VTX), flanked by two forward sections (FVTX). The ability to perform the DCA measurements leads to the following set of detector requirements:

- DCA resolution $< 50\mu m$ for the central barrel; $< 100\mu m$ for the forward detectors.
- Occupancy $< 10\%$ in central Au-Au collision in order to be able to find tracks.
- Large solid angle coverage: $|\eta| < 1.2$ for the barrel, standalone; $|\eta| < 0.35$ for barrel, when matched with Phenix central arm detectors; $1.2 < |\eta| < 2.4$ for forward detectors - this range covers most of the Phenix muon arms.
- Capability to match tracks with Central arm and Muon arm tracking systems.
- Sufficient number of hits $(>= 3)$ to find and reconstruct a track.
- Minimal mass

2. Description of the Devices
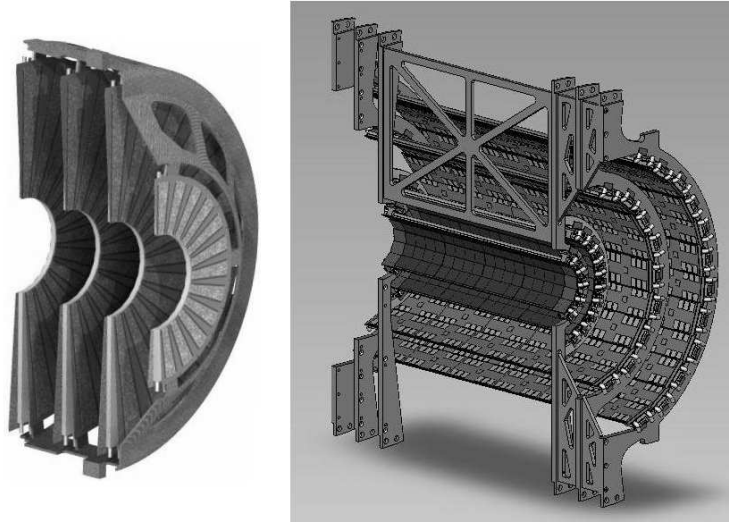
Figure 1. Left: one half of one endcap. Diameter is 40 cm. Right: one half of the barrel. Length 38 cm.Figures are not on the same scale

Figure 2 shows one half of one endcap, and half of the barrel detector.

The central barrel consists of 4 concentric layers. The inner two layers use hybrid pixel detectors originally developed by the Alice collaboration The pixel hybrids are $50 \times 425\mu m$, on $200\mu m$ thick silicon. The hybrids are mounted on ladders, with 10 ladders making up the first layer, and 20 forming the second layer. The radii of these

layers are 2.5 and 5.0 cm, and cover 22cm in length, for a total of 1.3 and 2.6M channels for layer 1 and 2, respectively. The readout is with the ALICE1LHCb chip [1], bump-bonded to detector. The total radiation length along the normal is 1.4%, and the track occupancies in central Au-Au collisions are expected t be 0.5 and 0.2%.

Figure 2. Left: A completed inner barrel half-ladder, read out by a prototype readout board

Current designs call for the outer 2 layers of the barrel to be constructed from stripixels [2]: each readout element measures $80 \times 1000 \mu m$, oriented parallel to the beam direction. Each element is read out along 2 directions, effectively providing small-angle stereo readout from a one-sided silicon. The silicon is $650 \mu m$ thick. The outer two barrels are at nominal radii of 10 and 14 cm, and have lengths of 32 and 38 cm, respectively. The total channel count is 420K channels, read out with SVX4 [3] chips. Radiation lengths are 2.7% per layer, and track occupancy in central Au-Au events is 4.6% and 2.6%.
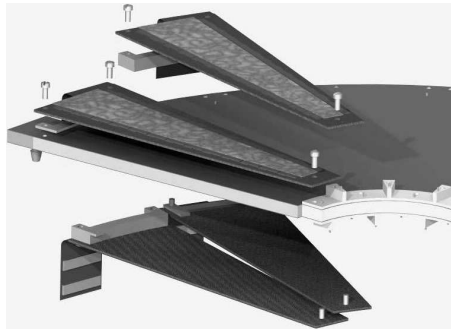
Figure 3. View of the FVTX disk assembly.

Each of the FVTX endcaps consists of 4 stations, with sensitive area between an inner radius of 4.5cm and outer radii of 10 cm for the first disk, and 18cm for the other three disks. As shown in Figure 3, each station consists of a honeycomb support disk, onto which are mounted 48 wedges, front and back. Each wedge carries a silicon detector, readout chips, and a high-density interconnect cable, mounted on a carbon-fiber support. The silicon on each wedge is divided into two columns of ministrips, at $75 \mu m$ pitch, 2.8mm long near the inner radius, up to 11.2 mm long at the outer radius. The total channel count for the endcap detectors is 1.1M channels. The strips are read out by newly developed FPHX [ref]chips, which are derived from the BTeV chip. Average area radiation length per disk is 2.4
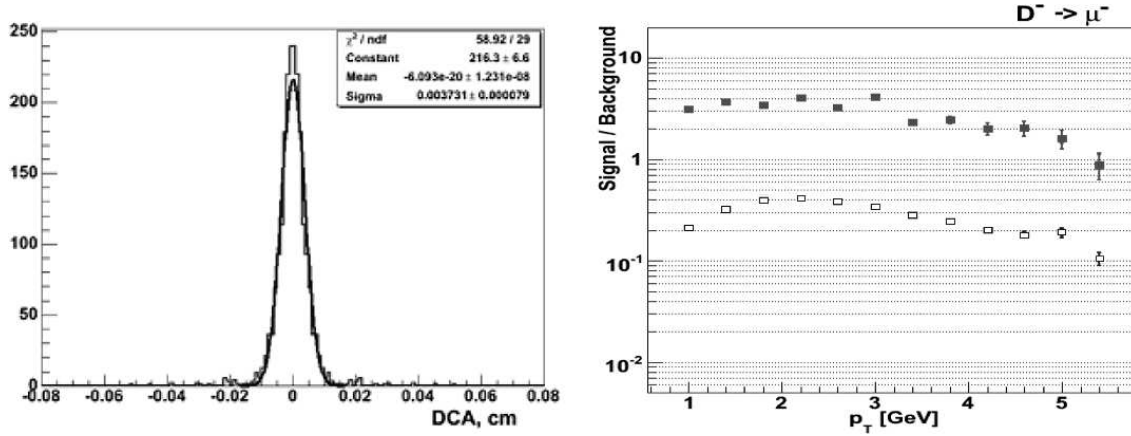
3. Selected Simulation Results

Figure 4. Left: expected DCA resolution in the barrel; sigma is $37\mu m$. Right: Improvement of the signal/noise for the $D^- \to \mu^-$ channel. Open symbols: S/N without the vertext tracker; solid: with the tracker.

Figure 3 shows selected results from Monte Carlo studies. The left panel shows the DCA distribution for single pions in the barrel in the range $3 < p_T < 4$ GeV/c. The distribution has a width of $\sigma = 37\mu m$. The right panel shows the signal/noise for the $D^- \to \mu^-$ channel. Open symbols show that S/N is below unity without the vertex tracker. Using the vertex tracker to exclude tracks with large DCA, corresponding predominantly to $\pi \to \mu$ and $K \to mu$ decays, as well as those with small DCA, and requiring close matches between track segments found in the silicon tracker, with muon candidates found in the Phenix muon Arms, the S/N ratio improves by an order of magnitude over the p_T range shown,

4. Status and Outlook

Both the barrel and the endcap sections of the detector are currently in the construction phase. The pixel layers of the barrel will be completed in 2009. Layers 3 and 4 of the barrel will follow the next year, and the endcaps will be installed in 2011. With each phase, a new window for exploration of the QGP properties will open.

References

[1] Front-end Pixel Chips for Tracking in ALICE and Particle Identification in LHCb. K. Wyllie et al., Proceedings of the International Workshop on Semiconductor Pixel Detectors for Particles and X-Rays (PIXEL2002)
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[3] SVX4: A New Deep-Submicron Readout IC for the Tevatron Collider at Fermilab. B. Krieger et al., IEEE 2003 Nuclear Science Symposium (NSS) and Medical Imaging Conference. IEEE Trans.Nucl.Sci.51:1968-1973,2004.